

Outer Planets / Grand Tour
RADIO SCIENCE TEAM REPORT (FINAL)

1 February 1972

1. Membership: J. D. Anderson, Jet Propulsion Laboratory
J. D. Davies, Jodrell Bank, Macclesfield, Cheshire, England
V. R. Eshleman (team leader), Stanford University
G. Fjeldbo, Jet Propulsion Laboratory
G. S. Levy, Jet Propulsion Laboratory
A. P. Mayo, NASA-Lewis Research Center, Hampton, VA
I. I. Shapiro, MIT, Cambridge, MA
G. L. Tyler (deputy team leader), Stanford University

2. Team Activities:

Meetings:

1. 11 May 71 at JPL - Anderson, Mayo and Tyler in attendance with Shapiro participating by telephone.
2. 10 June 71 at JPL - Anderson, Fjeldbo, Levy, Mayo and Tyler in attendance with Shapiro participating by telephone.
3. 26-27 August 71 at Stanford - Anderson, Eshleman, Fjeldbo, Levy, Mayo and Tyler in attendance.
4. 30 November - 1 December 71 at JPL - Anderson, Eshleman, Fjeldbo, Levy, Mayo, Shapiro and Tyler in attendance.

(The minutes of these meetings are attached.)

The JPL team representative for radio science was George Thompson through 1 December, and now is Paul Parsons.

3. Tasks Undertaken and Their Present Disposition

Since the scientific instrument for the radio science investigation is the communications and tracking radio system, most of the radio science tasks have been requested from the project on the assumption that they could be investigated at JPL by the transponder or navigation design groups.

(NASA-CR-136219) DEFINITION PHASE OF
GRAND TOUR MISSIONS/RADIO SCIENCE
INVESTIGATIONS STUDY FOR OUTER PLANETS
MISSIONS Final Report (Stanford Univ.)
29 p HC \$3.50
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63/30 24121
CSCL 22A

- a. Monopulse feed system. It has been concluded that this system is not required to meet the current engineering requirements. Investigation of possible alternative methods of measuring atmospheres below the 100 mb level are continuing (e.g., a programmed S/C maneuver with time of start controlled by measuring up-link signal strength).
- b. Medium gain antenna. It has been concluded that this system is not required to meet the current engineering requirements. The radio science team, in conjunction with the radio astronomy team, is continuing study of the potential scientific uses of such an antenna to see if it should be proposed as part of the science payload.
- c. On-board calibration of S-X transponder delays. It has been concluded that this system is not required to meet the current engineering requirements. The attention of the radioscience team is now directed toward minimizing such delays and understanding to what extent calibration before flight can be used to predict the delays.
- d. Reconstituted range code, and down-link-only differential ranging. It has been concluded that this system is not required to meet the current engineering requirements. The radio team is now studying how down-link-only differential range might be measured based on an autocorrelation measure of the science or other modulation which could be impressed on both the S-band and X-band carriers.
- e. S-band system temperature measurement for radio astronomy. Study by the team is continuing, but the project has no future implementation plans.
- f. Linear S-band polarization. Study by the team is continuing, but the project has no plans for further implementation studies.

- g. Oscillator stability and accuracy. Requirements for relativistic red-shift experiment appear to be beyond current feasibility. Study by the team is continuing relative to short-term stability requirements for upper-atmosphere measurements.
- h. Continuous S-X band signals for non-DSN site reception. Present plans call for continuous S-band but non-continuous X-band. Study by the team is continuing on scientific arguments for having both carriers on at all times, and on how such long-term operation might be achieved.
- i. On-board, low-level accelerometers. Study is continuing. No work has been done at JPL on such accelerometers, but Div. 34 has proposed a development plan for such work.

4. Science Objectives

- 1. Determine the temperature, pressure, and microwave absorptivity or loss profiles of planetary and satellite atmospheres from a pressure level of a few hundredths of a milibar down to the level of superrefraction or to the surface. Determine the mean molecular mass and hydrogen-helium ratio for planetary atmospheres below the turbopause. Find the frequency dependence of the microwave absorptivity or scattering loss.
- 2. Determine the electron concentration, principal ions, and plasma temperature as a function of height in planetary and satellite ionospheres and possible magnetospheres.
- 3. Measure a component of the magnetic field of Jupiter from high magnetospheric altitudes down to the lowest level of the ionosphere. Search for magnetic fields of other planets.

4. Determine the amount of material and a gross indication of the size of the particles in the rings of Saturn, and find the thickness and radial dimensions of the rings. Search for particle rings around other planets.
5. Determine the dielectric constant, surface material density, average slopes, and large and small scale roughness parameters for the surfaces of Pluto and several large satellites.
6. Attempt to discover solid surfaces or deep-atmospheric dielectric discontinuities for the major planets.
7. Determine planetary and satellite diameters, masses, mean densities, and gravity fields.
8. Attempt to determine the mass of Saturn's rings and the mass of the material in the asteroid belt.
9. Improve satellite and planetary ephemerides and determine the accurate location of the planetary system with respect to the external reference frame provided by quasars.
10. Determine the average value and the time and space variability of the electron concentration in the solar wind to great heliocentric distances, find the positions, dimensions, and speeds of discrete plasma clouds streaming out through this medium, and perhaps find the heliopause and the interstellar electron concentration near the solar system.
11. Determine density, structure, dynamics, velocity, and magnetic features of the solar corona during the yearly superior conjunctions of the GT spacecraft
12. Improve experimental tests of general relativity in time delay and ray bending experiments for propagation paths near the sun, and conduct other relativistic tests including those related to gravitational red shift and to the equivalence of inertial and gravitational mass of large planets.

13. Measure 13 cm- λ radio emission from the planets with high resolution using the communications receivers.

14. Discover unanticipated phenomena.

5. Measured Parameters

The observables on the radio signals propagated directly and via planetary or satellite reflections between the earth and the GT spacecraft are: relative phase path and dispersive differential phase path; group path and dispersive differential group path, amplitude and dispersive differential amplitude; polarization; frequency-amplitude spectrums at two wavelengths; and delay-amplitude spectrums at two wavelengths, all as a function of time. In addition, the radio noise can be measured at the spacecraft and reception of signals on earth may be at two locations for interferometric measures.

From these observables one can determine: the refractive index and absorption coefficient as a function of height in planetary and satellite atmospheres; the electron concentration as a function of height in ionospheres and magnetospheres; the longitudinal magnetic field strength integrated along the ray path in ionosphere and magnetospheres; the integrated refractive, absorptive, and scattering effects of particulate matter in satellite rings and possible planetary clouds; the integrated electron concentration and the longitudinal magnetic field strength of the interplanetary medium and solar corona on paths between the earth and GT spacecraft; the distance to discrete plasma clouds that intersect the raypaths; the range and range-rate (corrected for plasma errors) of the spacecraft and their angular positions relative to earth tracking stations (and the host of results in the area of celestial mechanics and relativity that this makes possible; the reflection coefficient and frequency and delay spreads of bistatic radar echoes from surfaces; the frequency and delay spreads due to small scale structure and motion in atmospheres and in the solar corona; and the radio emission temperature as a function of position on planetary discs.

Derived Parameters

Atmospheric refractivity profiles can be used to determine profiles which are proportional to pressure and temperature. The constants of proportionality are determined by the relative abundance of the atmospheric gaseous constituents. If abundances are known, actual temperature and pressure profiles are obtained. Conversely, other knowledge such as the temperature in the stratosphere or the temperature at a particular height in the atmosphere makes it possible to find the mean molecular mass. For the major planets, for example, the mean molecular mass yields the hydrogen-helium ratio if there are no appreciable amounts of other constituents. Inversion of occultation measures to height profiles of temperature and pressure assumes spherical symmetry, mixed non-polar atmospheric molecules, and hydrostatic equilibrium. For Venus, dual-frequency occultation measures have yielded temperature profiles which show more detail than the direct measures of the Venera spacecraft, and have an accuracy of better than 2.5% with the above conditions and assuming that the constituents are known. Comparing Mariner and Venera temperature measurements at common pressure altitudes shows that a light atmospheric constituent may be present (for example, 8% helium) with the major constituent, carbon dioxide. This conclusion could be made with assurance if the Venera temperature and pressure measurements were more accurate. The Mariner V absorptivity or loss profiles give important clues to what may be a condensate (but not water) cloud system below the visible clouds, and the temperature profiles add credence to the suggestion that the upper cloud system may consist of water-ice particles.

Refractivity profiles for upper atmospheres yield directly the electron concentration profile, assuming spherical symmetry in the limited region probed by the radio signals. Interference between ionospheric and atmospheric effects on the measurements will be avoided by the use of two coherent frequencies to separate dispersive ionospheric effects from non-dispersive atmospheric effects. Other information on likely upper-atmospheric constituents can lead to model studies based on photochemical reactions and dynamics to identify probable ionoc species and plasma temperatures.

Faraday polarization measurements give the product of electron concentration and longitudinal magnetic field strength integrated along the radio ray path. Since the integrated electron concentration is determined from phase and group path measurements, the magnetic component can be separated if there is a reasonable model for the relative spatial distribution of magnetic field and plasma. Previous Faraday measurements on the solar corona have given new information on magnetic field and plasma distributions even in the absence of separate plasma measurements. For the major planets, polarization measurements may make it possible to extrapolate magnetometer measurements to regions much closer to the planet than is possible with the in-situ experiment.

The detailed problem of scattering by the particles in the rings of Saturn is under investigation by the Team.

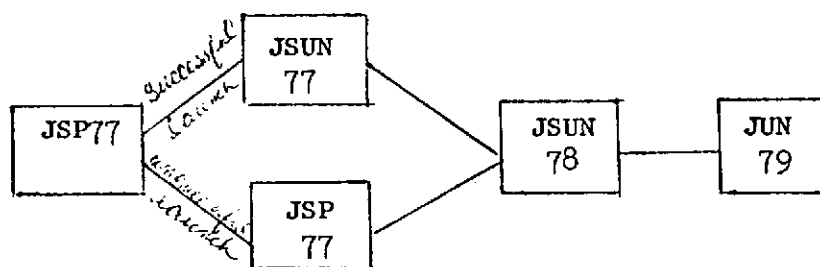
Dispersive phase and group path measurements between the earth and GT spacecraft give the integrated electron concentration along the path, as in the Pioneer 6-9 dual-frequency experiments. The GT missions will extend this technique to large heliocentric distances. The ability to measure low densities at great distances may require the determination of content differences to two GT spacecraft in nearly the same direction but at different ranges. Parameters related to large plasma cloud shapes and velocities depend upon multiple paths and on-board and near-earth plasma measurements. The positions of such clouds can be determined from autocorrelation measures of round-trip phase path. Small scale structure and solar wind velocity in the corona would be determined as in similar ratio star scintillation studies.

Range, range-rate, and angle measures of the spacecraft relative to earth tracking stations will yield results in the area of celestial mechanics and relativity for the outer planets which are similar to what has been obtained by other space missions and by radar for the inner solar system. Of particular importance is the increased accuracy afforded by the dual-frequency system, and the possible addition of great angular resolution to the measurements. More detailed considerations of this area will be supplied later.

The centroid of frequency-amplitude spectrums of echoes from the surface of a satellite is a measure of its radius, and the width of the central quasi-specular part of the echo is a measure of the product of average surface slopes and planetary rotation. The slopes can be separated if rotation is determined by television. Maps of slopes as a function of position on the moon determined by bistatic radar have been very favorably compared with detailed photographic results. The total power under the central region of frequency-amplitude spectrums is a measure of the reflectivity or dielectric constant of the surface, and hence proportional to the material density. Independent determination of the dielectric constant is possible with polarized measurements at the Brewster angle. The width of the wings of the spectrum can be used to find a small-scale roughness parameter for the surface and near sub-surface.

6. a. Trajectory Preference

Occultation is required for atmospheric measurements. Dense atmospheres can be probed to maximum depth if the flyby distance is minimized. The radio science team recommends the following mission set:



As a second choice, and in order to increase the science payload by reducing C_3 and having only one launch per window, we recommend



b. View angle requirements. Not applicable.

c. Required S/C Maneuvers.

At entry and exit from occultation, the S/C must change orientation to keep the high-gain antenna pointing near the limb of the planet at the position where the radio signal from the earth is refracted on its way to the spacecraft. Information for the maneuver would come either from the signal direction itself (in a monopulse system), or from the on-board computer with time of initiation being based on sudden changes in signal characteristics when the ray paths first encounter the atmosphere.

7. Minimum Experiment

The minimum experiment is based on the radio system characteristics of the minimum spacecraft, but not ruling out such characteristics as an adaptive maneuver to change antenna pointing at occultation, if such a maneuver can be implemented with relatively little impact on cost, weight, and power.

DATE: 15 June 1971

To : Members of the OPGT Radioscience Team

From : G. L. Tyler

Subject: Minutes of the First Meeting of the OPGT Radioscience Team

The first meeting of the Radioscience team was held May 11, 1971 in conjunction with the first OPGT science meeting at JPL. Team members in attendance were:

John Anderson
Gerry Levy
Alton Mayo
Irwin Shapiro (participated by telephone)
Leonard Tyler

The meeting was chaired by Leonard Tyler in the absence of the regular team leader, V. R. Eshleman.

The meeting was primarily devoted to a discussion of the general characteristics of the OPGT missions and their impact on Radioscience and Celestial Mechanics. This discussion centered on the range of possible experiments with particular consideration of those possibilities unique to the Grand Tour. Particular comments are given below:

- a) For Celestial Mechanics it is felt that the greatest gains, beyond the S-X system, will be achieved by the elimination of unmodelled spacecraft accelerations or the inclusion of low level accelerometers to measure those accelerations.
- b) VLBI may have considerable utility for OPGT navigation.
- c) A gravitational red-shift experiment would be possible with an on-board oscillator having absolute accuracy to one part in 10^{10} .
- d) Faraday rotation experiments will require the transmission of linear polarization at S-band.
- e) There is a potential gain for both Celestial Mechanics and Radioscience aspects of the Grand Tour mission through the use of non-DSN sites, e.g., Jodrell Bank or the Arecibo Observatory.

- f) The addition of a UHF downlink coherent with the S-X transmissions could improve sensitivity to changes in the total electron content in the interplanetary medium, planetary ionospheres sensed during occultation, and dispersive attenuation effects in neutral atmospheres, and also sensed during occultation.

In addition to these spacecraft related considerations, there was some discussion as to the mechanics of team operation:

- a) It is felt that through careful planning much of the engineering, tracking and navigation data reduction may be made compatible with the scientific requirements. Such coordination should be actively pursued.
- b) There is presently some uncertainty as to the relationship of the Radioscience team to other science teams such as radio astronomy where there may be some overlap in interest.
- c) The team also felt that it was poorly represented in the area of atmospheric physics and occultation technique.

As a result of the discussions, it was decided that the next meeting should consider in detail the present status of the radio system and the mission analysis. Gerry Levy was asked to arrange for presentation by JPL on these topics. The team will also request the addition of one member to represent the area of planetary atmospheres and occultation. Gunnar Fjeldbo is suggested for this role.

The next meeting is to be held the second week in June.

GLT:lwg

DISTRIBUTION:

V. R. Eshleman
J. D. Anderson
J. D. Davies
G. S. Levy
A. P. Mayo
I. I. Shapiro

T. Bird
G. Fjeldbo

DATE: 15 June 1971

TO : Members of the OPGT Radioscience Team

FROM : G. L. Tyler

SUBJECT: Minutes of the Second OPGT Radioscience Team Meeting

The second meeting of the Radioscience team was held during the morning and afternoon of June 10, 1971 at JPL. Team members in attendance were:

John Anderson
Gunnar Fjeldbo
Gerry Levy
Alton Mayo
Irwin Shapiro (participated by telephone)
Leonard Tyler

The meeting was also attended by the temporary experiment representative, Lou Paulos. The principal topics of discussion were the OPGT trajectory options, present and expected accuracy of the DSN radio range rate and range measurements, and the relationship of science objectives to observational requirements.

Lou Friedman and Paul Penzo gave a presentation on the results to date of the OPGT navigation team studies. The discussion brought out several points regarding the impact of the trajectory constraints on Radioscience. Viewgraph presentations were the same as shown on the All Science Meeting of May 10 and may be found in the distributed presentation materials from that meeting.

1. Commitment to JSP and JSUN trajectories will probably have to be made prior to Jupiter encounter. The JSP window is 76, 77, and 78 while the JSUN window is 77, 78, and 79. While the question of trajectory adaptation has not been studied in any depth, it is expected that a launch near the middle of the overlap period would provide the greatest flexibility in mission planning. It may be possible to retarget a '77 launch for a JSUN or JSP after a '76 launch arrives at Jupiter. Earlier JSUN missions have been previously ruled out to avoid flight through Saturn's rings. In general, JSUN missions involve very long flight times.
2. Satellite encounters are presently very difficult to achieve primarily due to the uncertainty in the satellite's position and masses. Since the present errors in satellite positions are at best a number of satellite diameters, occultations of

2. (continued)

the satellites may be impossible to achieve. If the positions were known the uncertainty in the masses is large enough to significantly impact the fuel budget for later mid-course corrections. Improvements in satellite masses and ephemerides from ground-based observations seem unlikely in the time period of the early OPGT mission, however, team members Anderson and Mayo believe the Pioneer F and G flybys may supply the requisite information. Relatively close encounters, 50,000 to 200,000 km, present no great difficulties.

3. The present mission design includes a trajectory correction maneuver 5-10 days prior to Jupiter encounter. This maneuver may seriously degrade the quality of the celestial mechanics encounter data. An on-board accelerometer to determine the maneuvering forces would permit the experimenters to connect the pre and post encounter maneuver data.
4. Present planning calls for S-X band tracking of one pass per week during cruise with continuous tracking for 80-day periods centered on trajectory encounters. The impact of such tracking on celestial mechanics experiments has not yet been determined. Radioscience studies of the interplanetary medium need nearly continuous tracking, but not necessarily by the DSN.

The DSN system accuracy presentation was given by George Thompson. The OPGT transponder is presently in the study phase. Mariner-class transponders will not be used because they cannot meet the reliability requirements. Current and anticipated DSN accuracies are given in Attachment 1. In the ensuing discussion it was pointed out that there are two distinct properties desired for the on-board oscillator:

1. The short-term stability for occultation measurements should be on the order of one part in 10^{10} to 10^{11} after the removal of known temperature and drift effects. Here, reproducibility of the oscillator frequency is not of critical importance.
2. For the red-shift experiment, the reproducibility of the oscillator frequency should be on the order of one part in 10^{10} to 10^{11} .

Alton Mayo distributed a handout (Attachment 2) which indicates that rubidium clocks weighing roughly 20 lbs. have been developed for space flight. It was agreed that such devices are impractical for OPGT. Gunnar Fjeldbo indicated the desirability of a non-coherent transponder

To: Members of the OPGT Radioscience Team - page three 15 June 1971

mode in which antenna pointing information would be derived from the uplink signal, as in the baseline design but, in which the downlink signal would be derived from the on-board oscillator. Such a mode may be a necessity for successful outer planet occultation studies.

Gunnar Fjeldbo presented Mariner 6 and 7 data that showed the detection of a bistatic-radar echo from Mars. This presentation stimulated a discussion on the possibilities of uplink data processing for similar studies from outer planet satellites or for use during occultation experiments.

As a result of these discussions it was decided to add studies of uplink data processing to the non-coherent transponder mode to the tasks previously submitted by the team leader for project consideration.

The remainder of the meeting consisted of a discussion of the preliminary experiment observations matrix (Attachment 3). This material will be revised by Tyler and transmitted to the team members.

GLT:lwg

DISTRIBUTION:

V. R. Eshleman
J. D. Anderson ..
J. D. Davies
G. Fjeldbo
G. S. Levy
A. P. Mayo
I. I. Shapiro
T. Bird
L. Paulos

DATE: September 21, 1971

TO : Members of the OPGT Radioscience Team

FROM : G. L. Tyler

SUBJECT: Minutes of the Third Meeting of the OPGT Radioscience and Celestial Mechanics Mission Definition Team

The third meeting of the OPGT Radioscience and Celestial Mechanics Mission Definition Team was held August 26 and 27, 1971 at Stanford University. The meeting was chaired by the team leader, Von Eshleman. Team members John Anderson, Gunnar Fjeldbo, Gerry Levy, Alton Mayo and Len Tyler attended. An agenda prepared by Eshleman provided the framework for discussion. Numbered topics given below correspond to the agenda items.

1. Grand Tour Politics

Eshleman described the evolutionary nature of scientific support for the Grand Tour projects and some of the identifiable forces working for modification of mission design within NASA Headquarters, JPL, and the OPGT SSG. It seems likely that the Jupiter radiation hazard and the funding squeeze will produce a considerable change in the baseline mission set and spacecraft. The so-called "PIO" spacecraft, presently under study by the project, is unacceptable for radioscience experiments because of its limited antenna and radio system capability. A change in the mission sets is potentially favorable to radioscience and celestial mechanics if they provide more flexibility for Saturn targeting. It was agreed that the team should actively consider alternative mission from its particular point of view. (Mission sets are discussed more fully under 6 below.)

2. Team Operations

A number of subjects relating to the mechanics of team activities were discussed with the following conclusions:

- A. Telephone Meetings - Telephone meetings will be used in the future on a trial basis.
- B. Jodrell Bank UHF Beacon Proposal - The team must have the active participation of the Jodrell Bank representative before it can consider giving its support to the UHF Beacon.
- C. Additional Representation - There are several areas where additional representation on the team would be desirable.
 - i. Radioscience is not sufficiently represented with respect to investigations of the interplanetary medium and with respect to the monitoring of the ionosphere over DSN sites.
 - ii. Celestial mechanics investigations could profitably utilize data from the spacecraft imaging system but has no direct representation. One imaging team member, Aksnes, will conduct investigation of the satellite systems. But celestial mechanics investigations could go beyond this.
 - iii. Radioscience and radio astronomy have overlapping interests and could profitably collaborate.

It was concluded that for the purposes of mission definition team, that these contacts should be handled on an ad hoc basis. The final teams (RS & CM, RA, Imaging) should have formal ties. Further, radioscience should have a representative with expertise in the interplanetary medium. These conclusions are to be formulized in the team's final report.

- D. Roles of the celestial mechanics representatives - The roles of the celestial mechanics experimenters are somewhat ill-defined, except for I. Shapiro whose central interest is in experimental tests of general relativity. Alton Mayo emphasizes planetary encounter experiments for the central body, and John Anderson expressed a broad interest in planetary encounter and interplanetary

cruise experiments. Mayo and Anderson agree that considerable mutual benefit will be derived from somewhat parallel albeit independent efforts in celestial mechanics.

3. Team Related Equipment Status

- A. Gerry Levy explained that project efforts to cut costs will likely result in a redefinition of the baseline antenna system. At present, the baseline antenna consists of a 14 ft. diameter unfurlable dish antenna with a monopulse feed. No decision as to whether the tracking loop will be closed on the ground or the spacecraft has been made. From a radioscience viewpoint, the tracking loop should be closed on the spacecraft. A 12 ft. diameter rigid antenna is under consideration. This antenna would not have an automatic tracking capability. The loss of the autotrack feature would seriously degrade radioscience occultation experiments.
- B.. The S-X breadboard system will undergo preliminary phase and group stability tests beginning in mid-September. The X-band system will be constructed separately and integrated on the spacecraft. Both systems are out for bid on flight hardware. Current work is for the Mercury-Venus and Viking Systems, and will be applied to the OPGT design.
- C. The project needs a request from the RS & CM Team to require on-board phase and group delay calibrations and to supply a downlink-only differential ranging capability.
- D. The block IV DSN receivers will have two programmable local oscillators (one uplink, one downlink).

- E. The DSN S-X feed is likely to be of the dichroic reflector type, utilizing two cones on the 64 m. antenna.
- F. Local monitoring of the ionosphere and atmosphere at the DSN sites is essential if ultimate tracking accuracies are to be achieved. There is no present plan for such monitoring.

4. Celestial Mechanics Discussion

John Anderson described the present uncertainties in the ephemerides and physical constants of the outer planets and their satellites. Current work to reduce these uncertainties was also discussed. Copies of four papers from the Astrodynamics Specialists Conference describing Grand Tour trajectory (mission) strategies were distributed. 1, 2,3,4

5. Non-DSN Receiving Sites

Several points were raised with respect to the use of non-DSN sites for scientific purposes.

- A. Radio astronomy installations in the United States and in other countries could perform useful experiments on the interplanetary medium and in the area of VLBI.
- B. John Anderson believes the planned one pass per week is sufficient for celestial mechanics purposes during cruise. Planetary encounters and superior conjunction experiments will require additional tracking.
- C. Solar corona and solar wind dynamics experiments are based on the use of two receiving sites.
- D. There is some concern as to the possibility of scientific scoop of radio team experiments by non-DSN sites.

E. NOAA may be interested in non-DSN sites for space weather.

6. Mission Sets (for Radioscience)

The accompanying table gives the current baseline mission set, the JPL SAG recommendation, plus three others suggested by the team. In general the RS & CM team favors JSUN missions since they provide Saturn occultation. A written discussion giving the arguments is to be prepared by Von Eshleman.

7. Satellites

The principal handicap in planning satellite encounter experiments is the uncertainty in their mass and ephemerides. On the basis of recent independent calculations reported by Mayo and Anderson, it seems possible that the Pioneer F and G encounters will provide a significant reduction in these uncertainties.

8. Surfaces

A. Len Tyler reported that a spacecraft/antenna maneuver and close satellite encounter would be required to obtain useful bistatic surface reflections. There seems to be little likelihood of obtaining reflections from the surfaces of the outer planets themselves. There is a possibility that the medium gain antenna could be used in an uplink mode to reduce maneuvering requirements, but this would require some on-board data processing. It may be possible to share equipment with the radio astronomy team for this purpose.

B. An on-board measurement of S-band system temperature would permit a 13 cm emission temperature scan of the planetary disks and would be very useful. Similar emission temperature measurements would be possible for the satellites, given a favorable geometry.

A bistatic (S-X band) scattering experiment from the rings of Saturn could be carried out from a JSU type mission. Such an

experiment would yield information on the particle size distribution of the particles in the rings, and the dimensions and content of the rings.

9. Saturn

Radioscience and celestial mechanics interests in Saturn impact the missions sets heavily. This problem is to be developed by Von Eshleman in a note on this subject.

10. Mission Definition Tasks

The team discussed the document "Preliminary Scientific Objectives" of the OPGT as stated in the SSG list. A number of changes were suggested.

The "Preliminary Summary, Radio Science Experiments OPGT Mission Definition" (9 July 1971) drafted by Von Eshleman was discussed briefly. This document will be revised by him in accordance with suggestions from the team members.

11. Serendipity

The team discussed possible experiments of opportunity unique to the OPGT. Among them were:

- A. Signal dropouts to search for small asteroids.
- B. Comet tail occultation.
- C. Long range occultation of the Moon or a planet.
- D. Search for new planets from improved ephemerides.
- E. Search for deep atmospheric discontinuities or surfaces for the major planets.

-7-

The meeting adjourned midafternoon on Friday. Additional convivial discussions were held Thursday evening at the home of the team leader.

ACTION ITEMS

- John Anderson
1. to determine details of baseline spacecraft mass expulsion attitude control system.
 2. to discuss possible cooperation in celestial mechanics between RS & CM and Imaging team with Aksnes.
 3. to determine applicability of asteroid formulae to independent small satellite encounters.
 4. to investigate detectability of red spot gravity anomaly.
 5. to investigate reliability of density figures for low density satellites.
- Len Tyler
1. to discuss possible cooperation in radioscience between RS & CM and Radio Astronomy Teams with Warwick.
 2. to determine articulation of medium gain baseline antenna.
 3. to compute uplink bistatic radar requirements.
- Alton Mayo
1. to verify perturbation calculations for small satellite encounters (asteroid results).
 2. to investigate detectability of red spot gravity anomaly.
- Gerry Levy
1. to supply documentation for subpart G, "State of Development of Experiment", Guidelines for Outer Planets Grand Tours Investigations Summaries.
- Fjeldbo
1. to investigate angular extent of ray path separations during planetary encounters.

- Von Eshleman
1. to visit LRC (Alton Mayo).
 2. to establish spacecraft design status review with George Thompson.
 3. to write OPGT project stating radioscience case for monopulse feed on fixed antenna.
 4. to document team requirements for
 - a) on-board calibrations of transponder phase and group delays
 - b) downlink-only group modulation.
 5. to levy requirements on project for local ionospheric and atmospheric monitoring at DSN sites.
 6. to request trajectory studies giving planetary and satellite occultations.
 7. to develop radioscience and celestial mechanics arguments on mission sets.

- ALL
1. to comment on project and team documentation by 20 September 1971.

References

1. "Grand Tour Mission Set Selection: Evaluation and Optimization," Kenneth Ledbetter, AAS 71-358.
2. "Satellite Encounter Opportunities of Grand Tour Missions," Paul Penzo, AAS 71-359.
3. "An Analysis of Approach Navigation Accuracy and Guidance Requirements for Grand Tour Missions", David W. Jones and Byron D. Tapley, AAS 71-374.
4. "Investigations of the Masses of the Outer Planets", P.K. Seidelman, R.C. Duncoube, W. J. Klepzynski, AAS 71-312.

All of the paper above were presented at the AAS/AIAA Astrodynamics Specialists Conference 1971, held Ft. Lauderdale, Florida, August 17-19, 1971.

MISSION SETS FOR OPGT

Mission Sets	R_{ψ}	T_{ψ}	R_{Δ}	T_{Δ}	R_{ϕ}	T_{ϕ}	R_P	T_P
Baseline	Radiation Belt ?							
76 JSP	1.1 ?	1.5	9.4	3.9			arb	9.8
77 JSP	2.9-4.7	1.3-1.5	3.3-10.7	2.8-3.3			↓	7.6/9.2
79 JUN(2)	5.0-12.6	1.3-1.7			1.4/3.5	5.1/7.1		8.6/11.4
SAG(JPL adv.grp.)								
77 JSP(2)								
79 JUN(2)								
Radio Team ?								
77 SSUN	11.2	2.2	3.2	4.2	5.5	8.7	arb	12.4
77 JSP								
a) 78 JSUN	25	1.7	3.2	3.6	6.2	8.0	arb	11.7
79 JUN								
77 JSP								
b) 78 JS								
79 JUN								
Pioneer H to								
JS or S								
c) 77 JSP								
79 JUN								

DATE: December 17, 1971

TO : Members of the OPGT Radioscience Team

FROM : G. L. Tyler

SUBJECT: Minutes of the Fourth Meeting of the OPGT Radioscience and Celestial Mechanics Mission Definition Team

The Fourth Meeting of the Outer Planets Grand Tour Radioscience Team was held November 30th and December 1st, 1971, at the Jet Propulsion Laboratory in Pasadena. The meeting was chaired by Von Eshleman. Team members, John Anderson, Von Eshleman, Gunnar Fjeldbo, Gerry Levy, Alton Mayo, Irwin Shapiro, and Len Tyler were in attendance. In addition, project representatives George Thompson and Lou Paulos were also present. Tom Bird and Ed Smith attended part-time. Regretfully this was the last meeting for the team representative, George Thompson, who is leaving JPL for a position elsewhere. At this time no new representative has been appointed by the project. The meeting generally followed an agenda supplied by the chairman. Agenda items appear as numbered subsections included in these minutes.^ω

1. Minutes of the Third Meeting

There were several comments regarding the minutes of the previous meeting.

- a) In reference to the spacecraft monopulse tracking system, the terms "closing the loop on the ground or on the spacecraft", refer to the technique used to correct spacecraft antenna pointing in response to errors sensed by the monopulse system; "closing the loop on the ground" implies that the necessary commands will be sent from the Earth; "closing the loop on the spacecraft" means the commands will be generated on-board.
- b) The table of mission sets included with the Minutes of the Third Meeting has an error in the last column. The last column should refer to the final planet reached as either Neptune or Pluto, not simply Pluto. With respect to serendipity, Irwin Shapiro felt that the search for new satellites was most likely to bear fruit. This possibility was not mentioned in the previous meeting. Irwin also wished to emphasize the need to be able to modify the tracking requirements for special occasions (e.g., close passage to a quasar).

2. SSG Activities

Von Eshleman gave a rather complete report on the activities of the SSG and his representation of the team before that group. Several actions of the SSG are of direct concern to the Radioscience Team.

^ω Items 11, 12 are not agenda items.

- a) In response to the dollar squeeze, the following changes have been made to the base-line spacecraft: the monopulse feed on the high gain antenna and the medium gain antenna have been deleted, the 14 foot unfurlable antenna has been changed to a 12 foot rigid antenna, and the X-band transmitter power has been reduced from 40 to 4 watts.
- b) JSP 76 has been deleted.
- c) The AFO release date has been moved to mid-March, 1972.
- d) The Space Science Board 1971 Woods Hole Summer Study has recommended full TOPS Radioscience capability.

In addition, the SSG is actively discussing options for mission sets. Saturn occultation (requiring JSUN) is of interest to at least one other science team, (UV spectrometer). Science Team reports are now due in January, 1972.

3. Report on OPGT Transponder Study Group Meeting

George Thompson reported on a joint meeting of the various transponder users. In summary:

- a) For navigation, a three-way dual frequency system is the presently stated Navigation Team requirement. The Navigation Team would like a two-way dual frequency system. In addition, greater $d\omega/d\beta$ stability ($1\sigma = 2$ meters at 20 AU) is desired. The Navigation Team would also like the continuous down-link dual frequency with ranging capabilities to simplify VLBI synchronization for tracking purposes.
- b) Radioscience desiderata include continuous down-link S/X beacons with reconstructed ranging, switched polarization, monopulse tracking, calibrated noise temperature measurements, and a stable on-board oscillator.

Von Eshleman commented that the motivation for the transponder meeting was to establish communication among the transponder users. Such a mechanism is required because of the rather exceptional position of radioscience with respect to other experiments. It was noted that there is also a Telecommunications Development Team (TDT) chaired by Gordon Wood with the responsibility for overall telecommunications systems development.

4. Status of the Hardware Development

Gerry Levy reported on the status of the hardware development. Particular emphasis was placed on the testing of the S/X systems for Mercury-Venus. Hardware development is proceeding very smoothly with excellent results. There have been significant changes in DSN planning. In particular, there has been some reduction of S/X support for Viking, but OPGT seems not to have been affected too drastically. For OPGT, the development of a long-lived X-band TWT is being held up by money constraints. TWTs presently under consideration for OPGT have rather limited life-time (~17,000 hours) that would preclude continuous operation.

Radio development, such as that required for continuous X-band operation, should be instigated by the project. At the present time radioscience needs are not making themselves felt. A RFP for OPGT prototype development is to be released January 1, 1972. The scope of this RFP is not clear and should be looked into by the team.

The team has received a letter from Ed Smith explaining project reasons for the deletion of monopulse system and the medium gain antenna from the new base-line spacecraft, based on overall weight and power arguments. A breakdown of the cost, weight, and power budgets is to be requested by the team.

5. Monopulse Feed System Alternatives

The chairman led a discussion on alternatives to the monopulse feed system for the occultation experiment. Gunnar Fjeldbo discussed the problem of tracking the occultation zone and indicated that the critical area is the timing of the effects. The principal alternative suggested was the use of the on-board computer to control the antenna pointing during occultation. The computer sequence would be initiated by a change in the up-link amplitude and/or frequency, or by a preset clock. Such a scheme would be expected to work quite well in the case of simple atmosphere and absence of multipath. For Jupiter, however, and possibly for the other outer planets, severe multipath propagation may be present. It is not known whether or not ionospheric effects would be incorrectly sensed as the start of the atmospheric ones. For Jupiter, Pioneers F and G should provide at least partial answers to these questions. It is clear that the entire question of the radioscience encounter strategy is extremely complex and requires not only a consideration of the atmospheric/ionospheric problems but the celestial mechanics problems of data contamination and encounter prediction as well. For the nominal JSP and JUN missions, the maximum predicted rate of change in doppler frequency and pointing angle are well within base-line spacecraft capability.

6. Medium Gain Antenna

The utility of a medium gain antenna for radioscience purposes is under investigation by Len Tyler. Preliminary encounter calculations have been carried out for bistatic radar experiments. It seems unlikely even under the most optimistic conditions that bistatic radar signals could be obtained from the giant planets themselves. However, it may be feasible to obtain bistatic radar echoes from the satellites of the planets. Further computations regarding the satellites are to be carried out for both the medium gain antenna and high gain antenna. In view of the considerable weight-power complexity associated with the medium gain antenna, it was decided that its inclusion in the spacecraft design would not be requested on the basis of radioscience alone.

7. Cost Estimate for Data Analysis

The team leader is to determine the ground rules for cost estimates from the project and present them to the team at the next meeting.

8. Science Management Plan

There were very few comments regarding the science management plan. Most of the team members had skimmed the document but had not yet had an opportunity to read it carefully. Principal comments were that:

- a) Radioscience is allotted 0. weight, 0. power and 0. dollars. This point may become an issue if the occultation experiment requires a supra-engineering radio system.
- b) Data analysis times of 6 months are unrealistic.
- c) The document conforms to the JSP/JUN mission set and does not have provisions for JSUN.
- d) Role statements for the Radioscience Team are contradictory. The Radioscience Team is constrained to abide by engineering decisions but at the same time is apparently required to sign-off on the radioscience instrument (telemetry system).

9. Draft Outline for Radioscience Experiments

The team leader is to revise the draft outline of the Radioscience experiment description and distribute it to the team members for review.

10. Action Items

A. From Third Set of Minutes:

- 1. John Anderson - Action items were completed with one exception: the determination of the details of the base-line spacecraft mass expulsion attitude control system.
- 2. Len Tyler - Action items are partially completed and are continuing.
- 3. Alton Mayo - Action items are completed but not in form for report. In addition, a study of the effect of tracking schedules on the determination of planetary gravity-field coefficients has been started. In general, these results seem to be in agreement with those of Null as reported by John Anderson.
- 4. Gerry Levy - Action items completed.
- 5. Gunnar Fjeldbo - Actions items completed.
- 6. V. R. Eshleman - Action items completed or of a continuing nature.

B. New Action Items:

- 1. Gunnar Fjeldbo - to compute doppler and antenna steering rates for JSUN 77 and 78.

2. V. R. Eshleman - a) to re-evaluate the stability requirements for the on-board oscillator, considering the trade-offs between long term and short term stability for radioscience purposes.
b) to obtain weight, power and dollar breakdown for high gain antenna monopulse and medium gain antenna
3. Gerry Levy - a) to distribute technical data on monopulse tracking system to team members.
b) to evaluate ramifications of base-line spacecraft changes for radioscience.
4. John Anderson - a) to make contact with the Navigation Development Team for the purpose of supplying radioscience inputs.
b) to coordinate error analysis studies with Alton Mayo.
c) to estimate a-priori encounter trajectory uncertainties with Irwin Shapiro.
5. Alton Mayo - to coordinate error analysis studies with John Anderson.
6. Irwin Shapiro - to estimate a-priori encounter trajectory uncertainties with John Anderson.
7. Len Tyler - to compute system temperature measurement parameters for outer planets.

11. Mission Sets

Von Eshleman presented arguments he has developed for an adaptive mission set and for mission sets containing JSUN. He will continue to press for a change in the mission sets in the SSG.

12. Report on Mariner 71

Irwin Shapiro reported briefly on the status of Mariner 71 experiments. The results on Demos and Phobos were particularly exciting. There was very little information, and most of that contradictory, on the Soviet results.